**Standard States & Standard Enthalpy of Formation**

|  |  |  |
| --- | --- | --- |
| ΔH can be determined by 3 different methods: | | |
| 1. using Calorimetry | **2. Using standard enthalpy of formation** | 3. Using Hess’s law |

**Standard Conditions**

Chemists have agreed to adopt standard ambient temp. and pressure (SATP) for thermochemical problems: T=\_\_\_\_\_\_\_\_\_, P=\_\_\_\_\_\_\_\_\_\_\_

**Standard State**

This is the state of a substance in which it naturally occurs at 25 0C and 1 atm. (ie. as a solid, liquid or gas)

Q. i) In which case is water in its standard state? H2O(s) H2O(l) H2O(g)

ii) Write the formula for the standard state of:

oxygen \_\_\_\_\_\_\_\_ lead iodide \_\_\_\_\_\_\_\_\_ sodium \_\_\_\_\_\_\_\_\_ carbon \_\_\_\_\_\_\_\_\_

**STANDARD ENTHALPY OF FORMATION, ΔHfo**

Definition:

ΔHfo = the heat of reaction which accompanies the formation of \_\_\_\_ mole of a substance from its **ELEMENTS** in their standard states (i.e. most stable form at standard conditions)

eg. ΔHf0 H2O(l) = -68.3 kcal The full meaning of this statement is equivalent to this equation:

H2(g) + ½ O2(g)----> H2O(l) ΔHf0 = -68.3 kcal

Note that:

\* 1 mole H2O is formed

\* H2O is formed from its elements: hydrogen, oxygen

\* each element is shown in its standard state; H2(g), O2(g)

⚫ ΔHfo for an element in its standard state is defined as **\_\_\_\_\_\_\_\_\_\_\_\_**

e.g. ΔHfo Cl2 (g) = \_\_\_\_\_\_\_ as at SATP, Cl2 is an **element** in its stable state which is gaseous.

⚫ The 7 diatomic molecules:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Find:

ΔHfo C(s) =\_\_\_\_\_\_\_\_\_ ΔHfo Fe(s) =\_\_\_\_\_\_\_\_\_\_ ΔHfo O2(g) =\_\_\_\_\_\_\_\_\_\_

**Q. Write the formation equation for CaO(s):**

A.

**Q. Explain why the following equations cannot represent ΔHf0 for CH4 (g)**

a) ½ C2H2(g) + 3/2 H2(g) ---> CH4(g) ΔH0 = -45.0 kcal

b) 2C(s) + 4 H2(g) ---> 2CH4(g) ΔH0 = -35.8 kcal

c) C(g) + 4 H(g) ---> CH4(g) ΔH0 = -226.3kcal

**Q. For practice, write formation equations for these compounds:**

1. C3H8(g) ΔHf = -25 kcal/mol

2.NO(g) ΔHf = 22 kcal/mol

3. Fe3O4(s) ΔHf = -267 kcal/mol

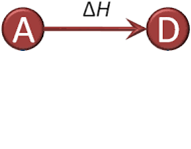
**Hess’s Law (1840)**

|  |  |  |
| --- | --- | --- |
| ΔH can be determined by 3 different methods: | | |
| 1. using Calorimetry | 2. Using standard enthalpy of formation | **3. Using Hess’s law** |

Recall: ∆H is a \_\_\_\_\_\_\_\_\_\_\_ function. (State function **≠**\_\_\_\_\_\_\_\_ function)

**Analogy**

|  |  |  |
| --- | --- | --- |
| **Bank account**  https://s3.amazonaws.com/lowres.cartoonstock.com/money-banking-beg-beggar-beggers-begging-tramp-jdon40_low.jpgSaving account balance: $2000  Thinking of withdrawing $ in May:   * Withdrawal scheme 1: 2 times; $500 each time * Withdrawal scheme 2: 1 time of $1000   Doesn’t matter how you withdraw;  Bank statement at the end of the month still shows a decrease of $1000 | Image result for how tall is cn tower**Climbing the CN tower**  Doesn’t matter if you take the stairs or use the elevator, it will take you the same elevation of ~356m to get to the sky walk platform | **Hiking**  The elevation is the same; it doesn’t matter which path you choose to go up |



**HESS’S LAW OF ADDITIVITY OF REACTION ENTHALPIES**

∆H of a physical or chemical process depends only on the\_\_\_\_\_\_\_\_\_ and \_\_\_\_\_\_\_conditions of the process.

∆H of a multistep process is the \_\_\_\_\_\_\_\_\_of the enthalpy changes of its individual steps

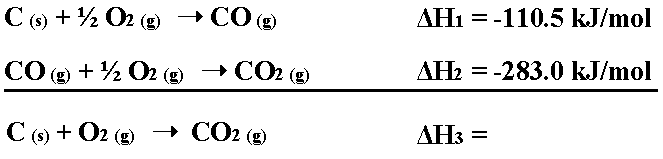
**∆Htarget = ∆H1  + ∆H2  + ∆H3 + ….**

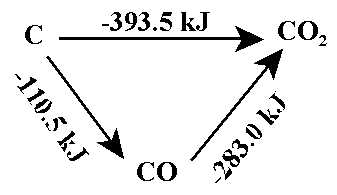
**Example 1:** Suppose you’d like to find the enthalpy change for the combustion of graphite (carbon) to carbon monoxide

**C (graphite) + O2 🡪 CO (g) (target reaction)**

-to cancel a compound, the sum of that compound’s coefficient in multiple reactions must =0

- rxns must be under the same conditions (use SATP conventions)

Two ways to get to the target reaction:



**Example 2:** Given the following equations and data:

**Recall:**

• Reverse a rxn,∆H’s sign also reverses • ∆H’s value depends on amt of rxt/product so x or **÷** by the

same coeff

S (s) + O2 (g) 🡪 SO2 (g) ΔH= -297 kJ/mol (1)

2 SO3(g) 🡪 2SO2 (g) + O2 (g) ΔH= 198 kJ/mol (2)

Find enthalpy change for the following equation: **2S (s) + 3O2 (g) 🡪 2 SO3 (g)**

**Practice Problems**

1. Find the ∆H for the following reaction below N2 (g) + O2 (g) → 2NO (g) ∆H = ?
2. ½ N2 (g) + O2 (g) → NO2 (g) ∆H = 34 kJ
3. NO(g) + ½ O2 (g) → NO2 (g) ∆H = -56 kJ
4. Use the following reactions and enthalpy changes to predict the standard enthalpy change for

2NO2 (g) + 2H2O (g) → 3 O2 (g) + N2H4 (g)

1. ½ N2 (g) + O2 (g) → NO2 (g) ∆H = 33.2 kJ
2. H2 (g) + ½ O2 (g) → H2O (g) ∆H = -241.8 kJ
3. N2 (g) + 2 H2 (g) → N2H4 (g) ∆H = 47.6 kJ
4. Given the following information
5. 2 ClF3 (g) + 2 NH3 (g) → N2 (g) + 6 HF (g) + Cl2 (g) ∆H = -1196 kJ
6. N2H4 (l) + O2 (g) → N2 (g) + 2H2O (l) ∆H = -622 kJ
7. 4 NH3 (g) + 3 O2 (g) → 2 N2 (g) + 6 H2O (l) ∆H = -1530 kJ

Determine ∆H° for the following reaction

3 N2H4 (l) + 4 ClF3 (g) → 3 N2 (g) + 12 HF (g) + 2 Cl2 (g)

1. How much energy can be obtained from the roasting of 50.0 g of zinc sulfide ore?

ZnS (s) + 3/2 O2 (g) → ZnO (s) + SO2 (g)

You are given the following thermochemical equations

1. ZnO (s) → Zn (s) + ½ O2 (g) ∆H = 350.5 kJ
2. S (s) + O2(g) → SO2 (g) ∆H = -296.8 kJ
3. ZnS (2) → Zn(s) + S (s) ∆H = 206.0 kJ

**Answers: 1) 180 kJ 2) 464.8 kJ 3) -2728 kJ 4) -226 kJ**

**USING STANDARD ENTHALPIES OF FORMATION** ∆H°f & **HESS’S LAW**

**WHY?** We can use ∆H°f to calculate the enthalpy change for almost any chemical reaction

**HOW?**

∆H°r = ∑(n∆H°f products) ̶ ∑(n∆H°f reactants)

where n represents the **stoichiometric coefficient** for each substance and ∑ means “the sum of”

**Use Appendix B p743 of your textbook to obtain molar enthalpies of formation value**

**Example 1: Find ∆H°comb  for the combustion of liquid benzene**

*Solution*

First, write a balanced combustion rxn for benzene

**Example 2: Find the standard enthalpy of the production reaction of H2S**

3H2 (g)  + SO2 (g) 🡪 H2S (g) + 2H2O (l)

*Solution*

**Example 3: Find the standard enthalpy of formation for urea CO(NH2)2**

Given: 2NH3 (g) + CO2 (g) 🡪 CO(NH2)2 (s) + H2O (l) **∆H°rxn = -133.5 kJ**

**Further Practice ∆H°f  & Hess’s Law:**

1. Find ∆H°f for glucose C6H12O6 given its heat of combustion ∆H°comb = -2803 kJ/mol

*[Ans:-1272.8 KJ/mol]*

1. Iron (III) oxide reacts with carbon monoxide to produce elemental iron and carbon dioxide. Determine the enthalpy change of the reaction *[Ans: -24.8 kJ]*

Fe2O3(s) + 3CO(g) → 3CO2(g) + 2Fe(s)

1. Ammonia reacts with oxygen according to the unbalanced equation:

NH3(g) + O2(g) → NO(g) + 2H2O(g)

Determine the enthalpy of reaction for this reaction *[Ans: -902 kJ]*

1. Chloroform, CHCl3(g), is formed from a reaction of methane and chloride. Determine the molar enthalpy of formation for chloroform *[Ans: -102.7 kJ/mol]*

CH4(g) + 3Cl2(g) → CHCl3(g) + 3HCl ∆H° = -305.0 kJ

***Multistep Calculation Question***

1. 21.9 kJ of energy is released when 5.48g of barium is oxidized to barium oxide, BaO(s). What is the enthalpy of formation of BaO(s)? *[Ans: -549 kJ/mol]*

Ba(s) + ½ O2(g) → BaO(s)

1. Consider the process: 3Fe3O4(s) + 8Al(s) → 9Fe(s) + 4Al2O3(s)
2. What is the enthalpy of reaction? *[Ans: -3347.6 kJ]*
3. What amount of heat would be released when 1kg of iron is produce? *[Ans: 6660 kJ]*
4. How much heat is required to decompose 500g of calcium carbonate, CaCO3(s)? *[Ans: 895.9 kJ]*

CaCO3(s) → CaO(s) + CO2(g)